

WHAT IS CLAIMED IS:

- 1 1. A process of operating a vertical glass bead furnace, the furnace
- 2 including a shaft open at the bottom, a raw material addition device, and an air-
- 3 fuel burner, comprising the steps of:
- 4 firing the air-fuel burner and thereby entraining air into the furnace
- 5 shaft through the open bottom of the shaft;
- 6 adding raw material into the furnace; and
- 7 an additional step selected from the group consisting of
- 8 (a) injecting oxidant into the shaft adjacent to the shaft bottom
- 9 using a single lance;
- 10 (b) operating an oxy-fuel burner in the shaft adjacent to the
- 11 shaft bottom;
- 12 (c) injecting oxidant into the shaft adjacent to the shaft bottom
- 13 using multiple lances;
- 14 (d) injecting oxidant into the shaft using a lance incorporated
- 15 into the air-fuel burner; and
- 16 (e) injecting oxidant into the shaft adjacent to the shaft bottom
- 17 using an oxidant injection ring.

1 2. A process in accordance with Claim 1, wherein the additional step
2 comprises injecting oxidant into the shaft adjacent to the shaft bottom using a
3 single lance.

1 3. A process in accordance with Claim 2, wherein the step of injecting
2 oxidant using a single lance comprises injecting oxidant upward along the center
3 of the furnace.

1 4. A process in accordance with Claim 2, wherein the step of firing an
2 air-fuel burner comprises firing with an equivalence ratio E , $0.7 \leq E \leq 1.0$.

1 5. A process in accordance with Claim 2, wherein the step of injecting
2 oxidant using a single lance comprises injecting oxidant at a velocity between
3 about 500 ft/s and about 800 ft/s.

1 6. A process in accordance with Claim 1, wherein the additional step
2 comprises operating an oxy-fuel burner in the shaft adjacent to the shaft bottom.

1 7. A process in accordance with Claim 6, wherein the step of
2 operating an oxy-fuel burner adjacent to the shaft bottom comprises operating an
3 oxy-fuel burner with a flame stoichiometry R , with $0.5 \leq R \leq 2.0$.

1 8. A process in accordance with Claim 6, wherein the step of
2 operating an oxy-fuel burner adjacent to the shaft bottom comprises operating an
3 oxy-fuel burner directed upward along the center of the furnace.

1 9. A process in accordance with Claim 1, wherein the additional step
2 comprises injecting oxidant into the shaft adjacent to the shaft bottom using
3 multiple lances.

1 10. A process in accordance with Claim 9, wherein the step of injecting
2 oxidant into the shaft adjacent to the shaft bottom using multiple lances comprises
3 injecting oxidant at a velocity between about 1 ft/s and about 100 ft/s.

1 11. A process in accordance with Claim 9, wherein the step of injecting
2 oxidant using multiple lances comprises injecting at an angle α relative to the
3 vertical axis of the furnace, with $0^\circ \leq \alpha \leq 80^\circ$.

1 12. A process in accordance with Claim 1, wherein the additional step
2 comprises injecting oxidant into the shaft using a lance incorporated into the air-
3 fuel burner.

1 13. A process in accordance with Claim 12, wherein the step of
2 injecting oxidant into the shaft using a lance incorporated into the air-fuel burner
3 comprises injecting oxidant at a velocity between about 30 ft/s and about 100 ft/s.

1 14. A process in accordance with Claim 1, wherein the additional step
2 comprises injecting oxidant into the shaft adjacent to the shaft bottom using an
3 oxidant injection ring.

1 15. A process in accordance with Claim 14, wherein the step of
2 injecting oxidant into the shaft adjacent to the shaft bottom using an oxidant
3 injection ring comprises injecting oxidant at a velocity between about 30 ft/s and
4 about 200 ft/s.

1 16. A process in accordance with Claim 14, wherein the furnace has an
2 internal diameter D_F , and wherein the step of injecting using an injection ring
3 comprises injecting using an injection ring having an external diameter D_R , and
4 wherein $0.2 \leq D_R/D_F \leq 0.9$.

1 17. A vertical glass furnace comprising:
2 a shaft having an interior space and open at the bottom;

3 a raw material addition device mounted so add raw material to the
4 interior of the shaft;

5 an air-fuel burner; and

6 an additional device selected from the group consisting of:

7 (a) a single oxidant injection lance adjacent to the shaft bottom
8 useful for injecting oxidant into the shaft;

9 (b) an oxy-fuel burner in the shaft adjacent to the shaft bottom;

10 (c) multiple oxidant injection lances adjacent to the shaft bottom
11 useful for injecting oxidant into the shaft;

12 (d) a lance incorporated into the air-fuel burner; and

13 (e) an oxidant injection ring positioned for injecting oxidant into
14 the shaft adjacent to the shaft bottom.

1 18. A vertical glass furnace in accordance with Claim 17, wherein the
2 device comprises a single oxidant injection lance adjacent to the shaft bottom
3 useful for injecting oxidant into the shaft.

1 19. A vertical glass furnace in accordance with Claim 18, wherein the
2 furnace has a center, and wherein the single lance is directed upward along the
3 center of the furnace.

1 20. A vertical glass furnace in accordance with Claim 17, wherein the
2 device comprises an oxy-fuel burner in the shaft adjacent to the shaft bottom.

1 21. A vertical glass furnace in accordance with Claim 20, wherein the
2 furnace comprises a center, and wherein the oxy-fuel burner is directed upward
3 along the center of the furnace.

1 22. A vertical glass furnace in accordance with Claim 17, wherein the
2 device comprises multiple oxidant injection lances adjacent to the shaft bottom
3 useful for injecting oxidant into the shaft.

1 23. A vertical glass furnace in accordance with Claim 22, wherein the
2 furnace has a vertical axis, and wherein the multiple lances are each oriented to
3 inject at an angle α relative to the vertical axis of the furnace, with $0^\circ \leq \alpha \leq 80^\circ$.

1 24. A vertical glass furnace in accordance with Claim 17, wherein the
2 device comprises a lance incorporated into the air-fuel burner.

1 25. A vertical glass furnace in accordance with Claim 17, wherein the
2 device comprises an oxidant injection ring positioned for injecting oxidant into the
3 shaft adjacent to the shaft bottom.

- 1 26. A vertical glass furnace in accordance with Claim 25, wherein the
- 2 furnace has an internal diameter D_F , wherein the injection ring has an external
- 3 diameter D_R , and wherein $0.2 \leq D_R/D_F \leq 0.9$.